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Haugen

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(54) **METHODS AND APPARATUS FOR SUSPENSION LOCK OUT AND SIGNAL GENERATION**

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B60G 2400/7162 (2013.01); B60G 2500/104
(2013.01); B60G 2600/72 (2013.01)

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280/124.16

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(58) **Field of Classification Search**

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See application file for complete search history.

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(56) **References Cited**

U.S. PATENT DOCUMENTS

(21) Appl. No.: **14/180,206**

4,659,104	A *	4/1987	Tanaka et al.	280/6.158
4,821,852	A	4/1989	Yokoya	
5,080,392	A *	1/1992	Bazergui	188/266.4
5,396,973	A	3/1995	Schwemmer et al.	
5,467,280	A *	11/1995	Kimura	701/37
5,996,745	A	12/1999	Jones, Jr. et al.	
6,151,930	A	11/2000	Carlson	
6,502,837	B1 *	1/2003	Hamilton et al.	280/5.515
6,659,240	B2	12/2003	Dernebo	
6,959,921	B2	11/2005	Rose	

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Related U.S. Application Data

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(Continued)

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Primary Examiner — Toan To

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B60G 13/14	(2006.01)
B62K 25/08	(2006.01)
F16F 9/06	(2006.01)
F03G 1/00	(2006.01)

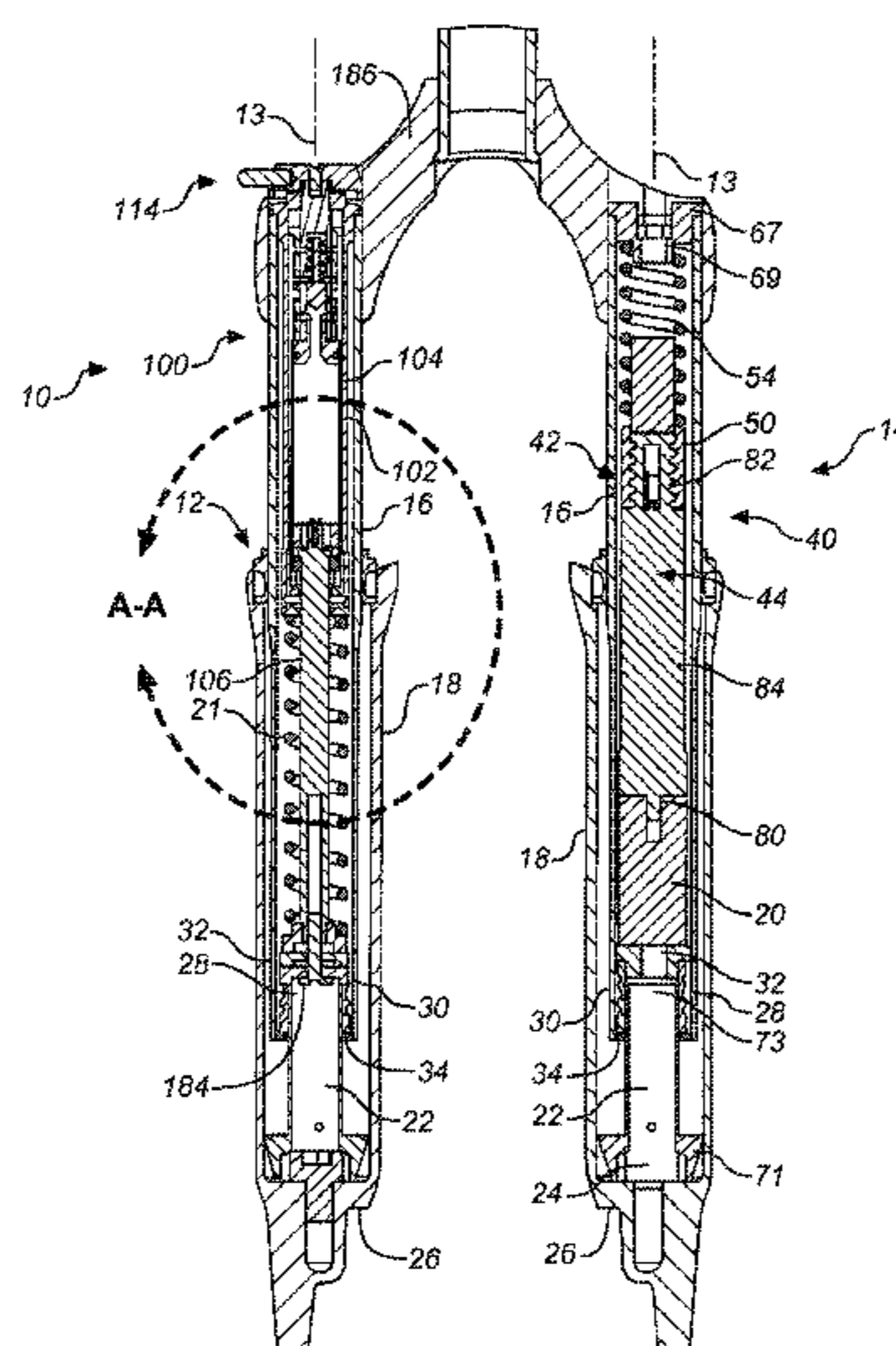
(57) **ABSTRACT**

Methods and apparatus for regulating the function of a suspension system are disclosed herein. Suspension characteristics often contribute to the efficiency of a suspended system. Depending on the desired operating parameters of the suspended system, it may be desirable to alter the functional characteristics of the suspension from time to time in order to maintain or increase efficiency. The suspension hereof may be selectively locked into a substantially rigid configuration, and the damping fluid may be phase separated and/or cooled to increase damping rate during use (or offset rate degradation). The suspension hereof may generate power usable to achieve any or all of the foregoing or to be stored for use elsewhere in the suspended system or beyond.

(52) **U.S. Cl.**

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F03G 1/00 (2013.01); **B60G 2204/4604**
(2013.01); **B60G 2204/61** (2013.01); **B60G**

2 Claims, 6 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

7,076,351	B2	7/2006	Hamilton et al.	2003/0001346	A1*	1/2003	Hamilton et al.	280/5.515
7,234,575	B2	6/2007	Anderfaas et al.	2003/0051954	A1	3/2003	Sendra	
7,413,063	B1	8/2008	Davis	2003/0075403	A1	4/2003	Dernebo	
7,600,616	B2	10/2009	Anderfaas et al.	2005/0121269	A1	6/2005	Namuduri	
7,722,056	B2*	5/2010	Inoue et al.	2005/0199455	A1	9/2005	Browne et al.	
7,931,132	B2	4/2011	Braun	2007/0119669	A1	5/2007	Anderfaas et al.	
8,056,392	B2	11/2011	Ryan et al.	2009/0071773	A1	3/2009	Lun	
8,393,446	B2	3/2013	Haugen	2009/0171532	A1	7/2009	Ryan et al.	
8,413,773	B2	4/2013	Anderfaas et al.	2009/0294231	A1	12/2009	Carlson et al.	
2001/0042663	A1	11/2001	Marking et al.	2010/0032254	A1	2/2010	Anderfaas et al.	
				2010/0066051	A1	3/2010	Haugen	
				2010/0170760	A1*	7/2010	Marking	188/299.1

* cited by examiner

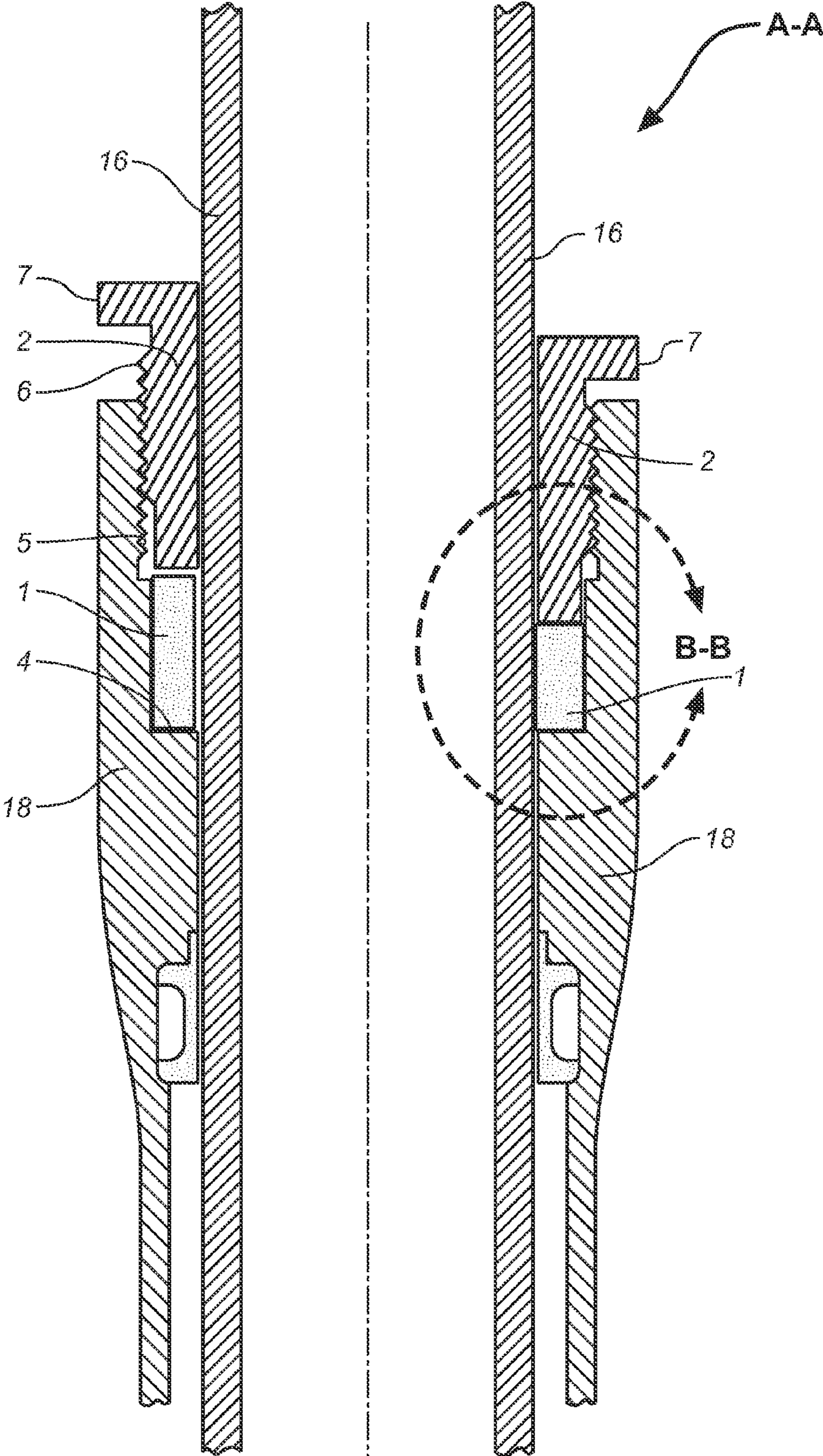


FIG. 2

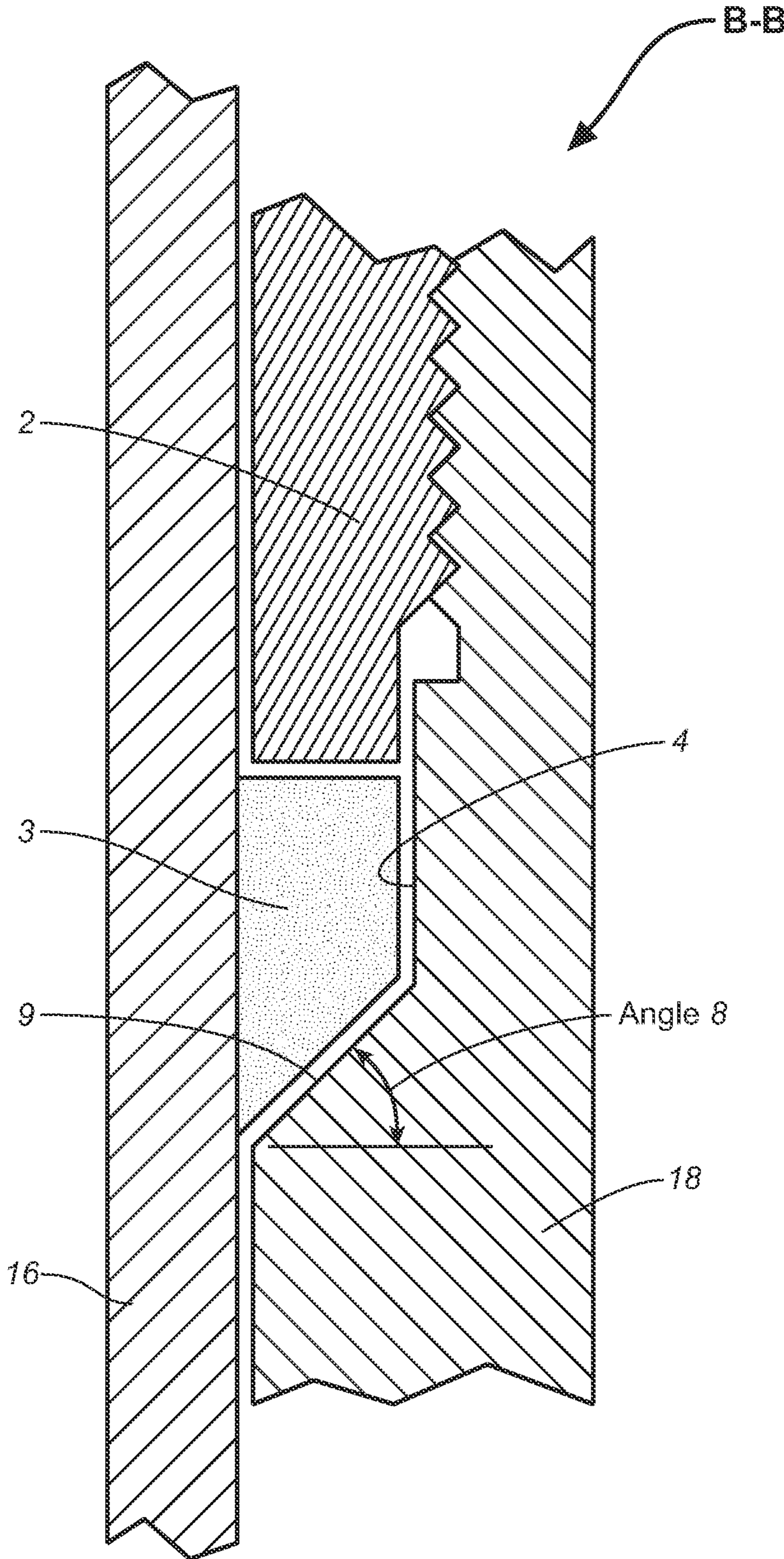


FIG. 3

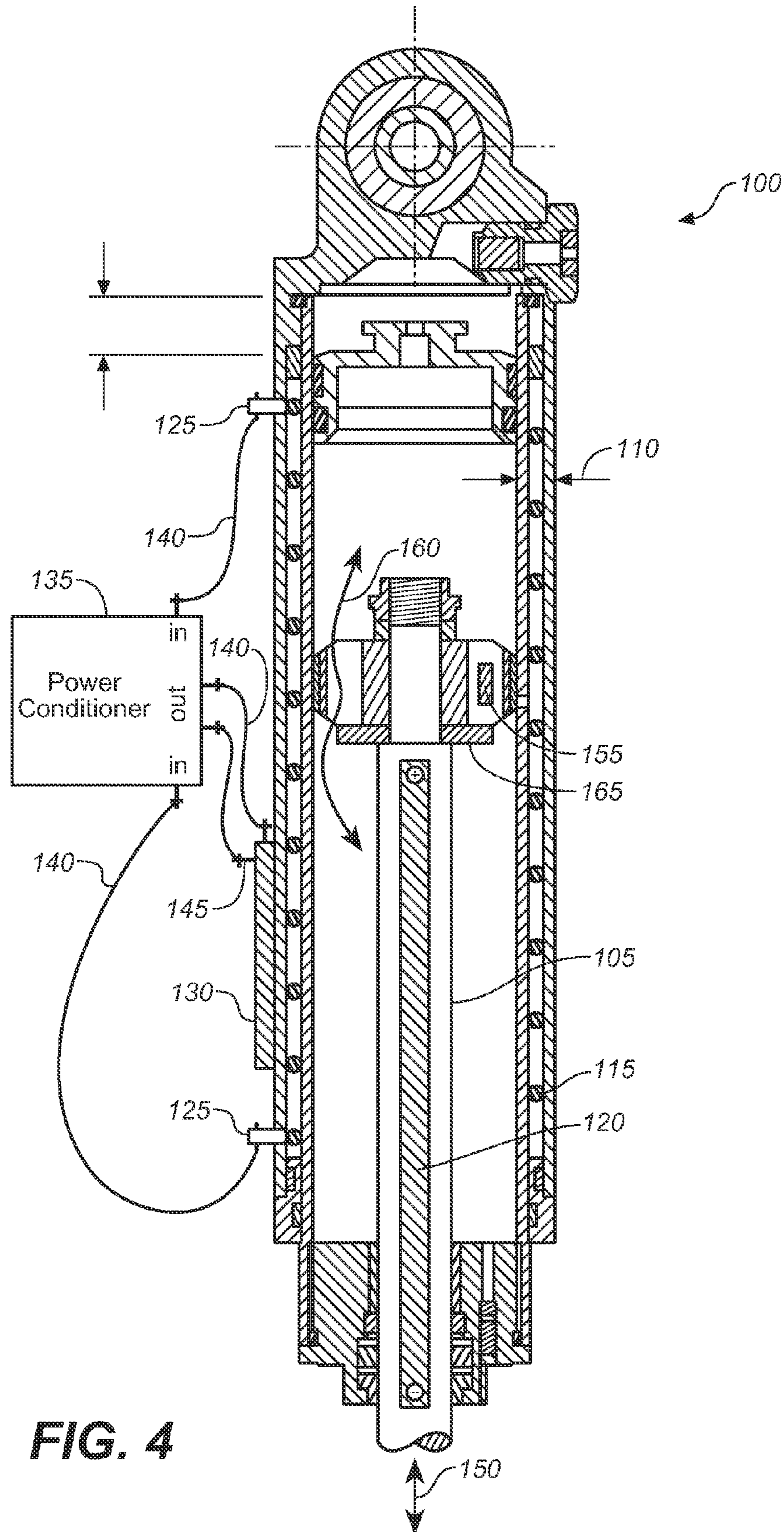


FIG. 4

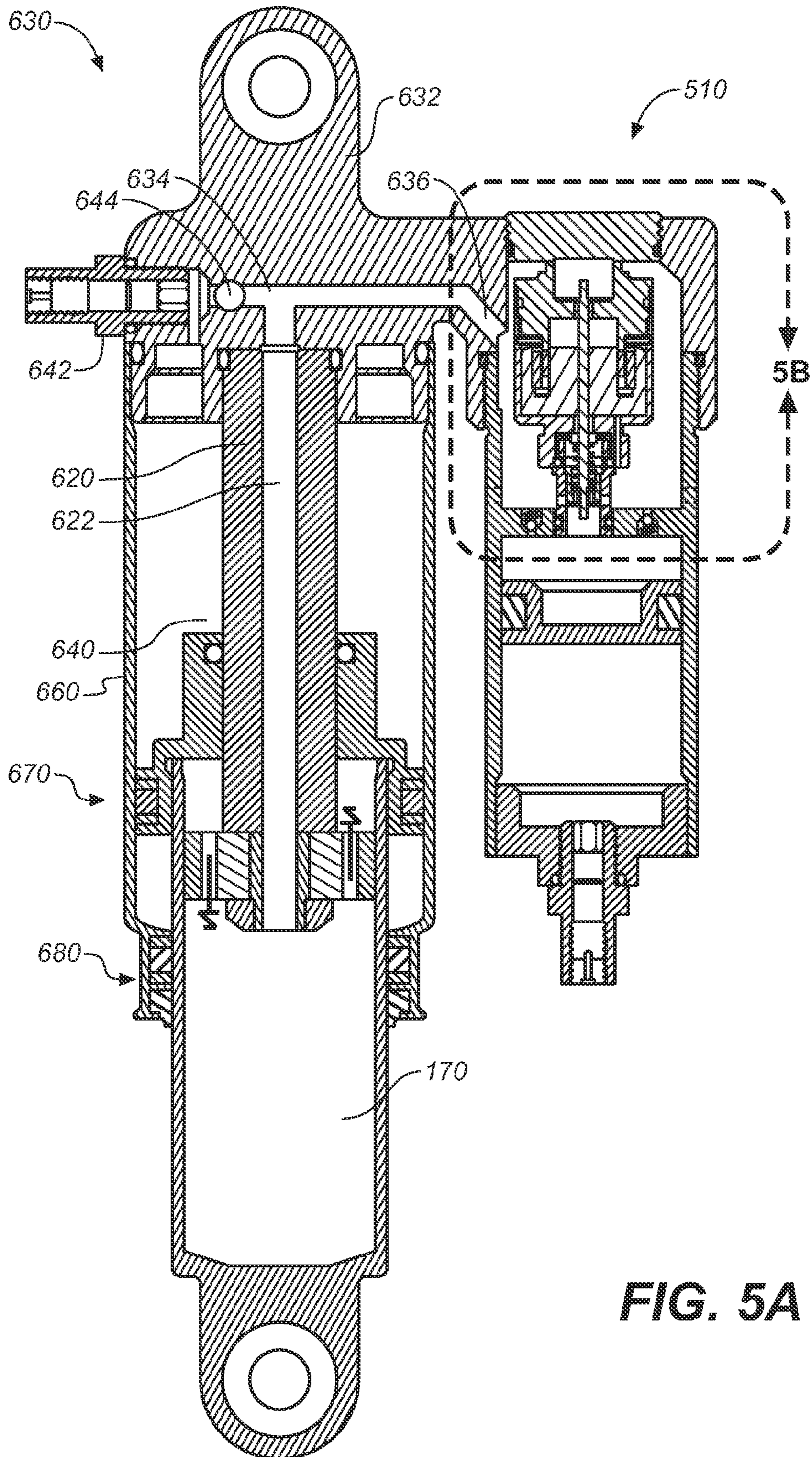


FIG. 5A

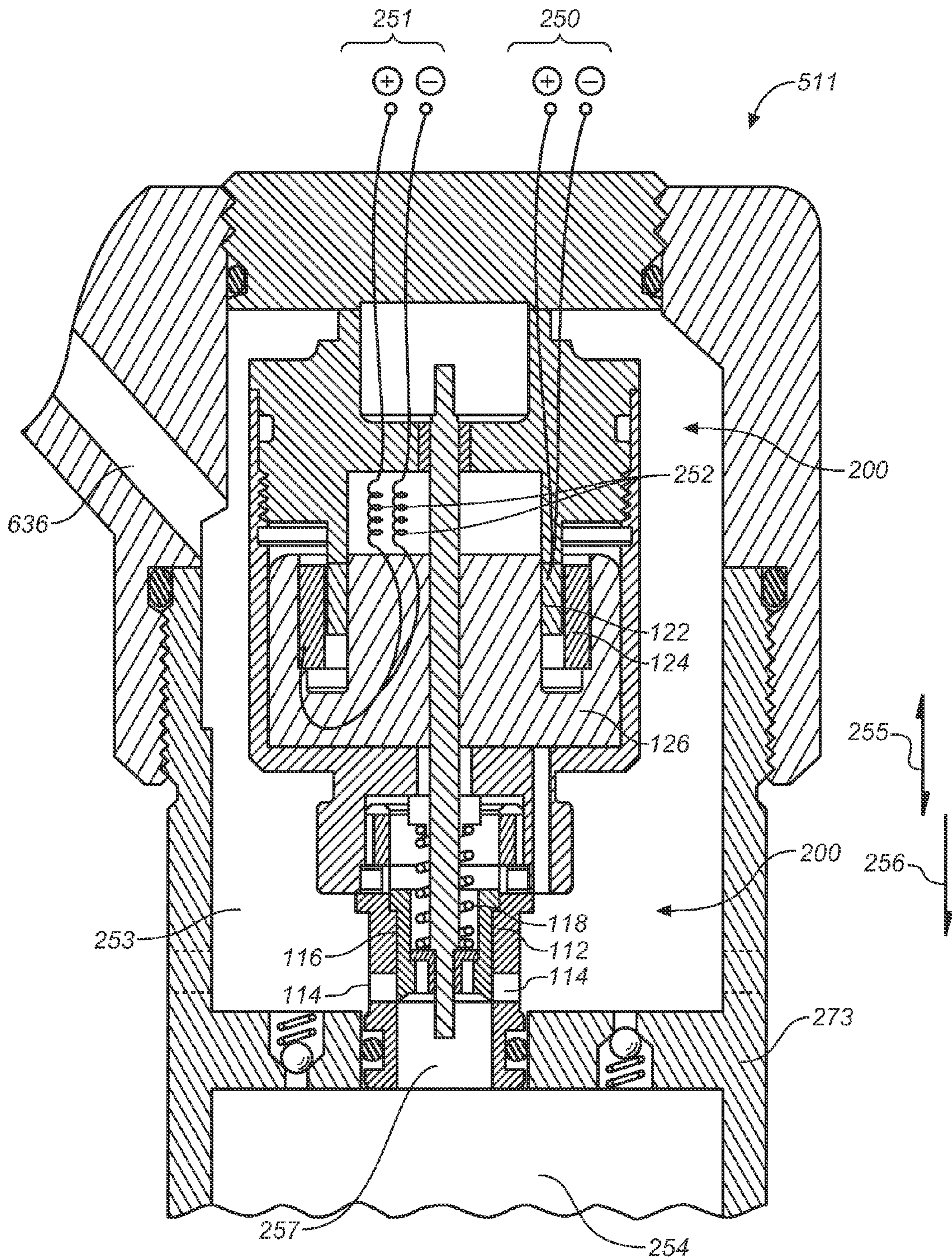


FIG. 5B

METHODS AND APPARATUS FOR SUSPENSION LOCK OUT AND SIGNAL GENERATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of and claims the benefit of co-pending U.S. patent application Ser. No. 13/761,555 filed on Feb. 7, 2013 entitled "METHODS AND APPARATUS FOR SUSPENSION LOCK OUT AND SIGNAL GENERATION" by David M. Haugen, and assigned to the assignee of the present application, which is incorporated herein, in its entirety, by reference.

The U.S. patent application Ser. No. 13/761,555 is a continuation application of and claims the benefit of U.S. patent application Ser. No. 12/547,381 filed on Aug. 25, 2009 and is now issued U.S. Pat. No. 8,393,446, entitled "METHODS AND APPARATUS FOR SUSPENSION LOCK OUT AND SIGNAL GENERATION" by David M. Haugen, and assigned to the assignee of the present application which is incorporated herein, in its entirety, by reference.

The U.S. Pat. No. 8,393,446 claims priority to and benefit of U.S. Provisional Patent Application 61/091,640 filed on Aug. 25, 2008 entitled "MECHANICAL SUSPENSION LOCK OUT" by David M. Haugen, which is incorporated herein, in its entirety, by reference.

FIELD OF THE INVENTION

Embodiments of the invention generally relate to methods and apparatus for selectively operating a suspension component. Some embodiments relate to generating a signal and/or current while operating a suspension component.

BACKGROUND OF THE INVENTION

Suspension systems and more particularly vehicle and bicycle suspension systems have been available for many years. The predominant form of vehicle suspension, and more specifically, bicycle suspension dampers, are telescopic. Suspension systems typically comprise a spring for energy storage and a damping mechanism for energy dissipation. Suspension systems are used to absorb impact and/or vibration in a wide variety of configurations including vehicle seats, vehicle wheels, industrial machinery, watercraft hull/cabin or cockpit interface, bicycle seat posts and many others. Vehicle wheel suspension often includes a damping mechanism for dissipating energy (from wheel movement caused by disparities in the terrain over which the vehicle travels) and a spring mechanism for storing energy for rebound. Damping assemblies often convert wheel movement into heat by means of fluid friction in a fluid filled dashpot (piston and cylinder) type damping device. Spring mechanisms may take many forms including, coiled springs, elastomer bumpers, compressible fluid (e.g. gas, silicone oil), suitable combinations thereof or other suitable energy storage mechanisms. Two wheeled vehicle front forks and rear shocks are designed such that a dampening piston is slidably contained within a cylinder. The cylinder typically contains a damping fluid (e.g. liquid oil) or fluids and the piston typically includes a valve or orifice through which the fluid flows from one side of the piston to the other as the piston moves axially within the cylinder. In typical bicycle suspension forks there are two cylinders and two pistons with one each paired telescopically on either side of a front wheel. Bicycle suspension forks are described in U.S. Pat. Nos. 6,217,049 and 5,186,481, each of

which patents is incorporated herein, in its entirety, by reference. A bicycle rear shock unit is described in U.S. Pat. No. 7,147,207 which is incorporated herein, in its entirety, by reference.

When a bicycle is equipped with front or rear suspension or both, it will tend to "bounce" in response to the cyclical force exerted on the pedals. There a couple of reasons for that but the result of any bounce is power loss. Suspension "squat" power loss on motorized vehicles may not be significant because the horsepower available is often more than adequate to compensate for the loss while still providing ample usable power. That may not be true of human powered vehicles such as bicycles. A typical adult human in good physical condition can supply approximately one half horsepower to the peddle crank of a bicycle. An elite athlete may supply horsepower approaching 0.6. In any case that isn't much horsepower and any loss is usually noticeable.

Another power loss mechanism involved is that of "chain power squat." When, for example, a chain exerts a forward directed pulling force on the rear sprocket of the bicycle, that force vector will tend to upwardly rotate a rear suspension swing arm about its pivot point at the frame connection if the chain, as it runs between the drive (chain ring) and driven (rear) sprockets, extends above the pivot point. Most often the chain does run above the pivot point and as force is exerted on the chain some of the force is expended in compressing the rear suspension (as the swing arm rotates due to the chain moment).

Another power loss mechanism is the force induced bounce that directly results from the rider's interaction with the pedals. A bicycle rider can usually exert more force downwardly on a pedal than upwardly. That means that the maximum force exerted on the bicycle power crank moves alternately from side to side of the bicycle laterally, as each pedal is pushed through a down stroke. The asymmetric and cyclical nature of the peddling action induces some bounce in both front and rear suspension units on a bicycle. As previously discussed, compression of suspension requires power. That power comes from one source on a bicycle and that is the rider.

In order that a bicycle rider may maximize the power delivered to driving the bicycle forward and minimize suspension compression waste (due to pedal "bob" and/or "squat"), there is a need for suspension units that can act as rigid units when suspension characteristics are not required, yet act to provide shock absorbsion when needed.

As previously mentioned, vehicle suspension systems are often damped by means of a piston traversing a liquid (e.g. hydraulic oil) filled cylinder arrangement. In such arrangement the piston is forced, alternatingly by terrain induced compressive loads and spring induced extension loads, through the liquid filled cylinder in response to operation of the suspension. Impact energy imparted to the suspension by terrain variation is dissipated by the damping system in the form of heat. Heat, generated by friction between the damping fluid and the traversing piston, builds up in the damping fluid and surroundings as the suspension is cycled. When the suspension is used vigorously, the heat build up can exceed the natural rate of heat transfer from the suspension to the surrounding atmosphere. Such heat build up can adversely affect the operation of the suspension damper. For example, the heat build up in the damping liquid will correspondingly change (e.g. lower) its viscosity and/or shear strength. Such changes can affect the damping force generated (and energy dissipation) by the damping piston during operation and may render the damping mechanism ineffective.

Accordingly there is a need for a selectively rigid suspension unit. Further, there is a need for a suspension unit that can be placed in a rigid condition without relying on hydraulic or other fluid lock out. There is a need for a vehicle suspension having increased heat dissipation characteristics. Further there is a need for a vehicle suspension unit that can convert vehicle movement to electric power. Further there is a need for a vehicle suspension unit that can use power generated therein to increase performance of the suspension.

SUMMARY OF THE INVENTION

Some embodiments of the present invention include methods and apparatus for mechanically fixing one part of a suspension mechanism to another part of the suspension mechanism such that the parts are substantially unmovable in relation to each other. Some embodiments include methods and apparatus for converting induced suspension movement into usable and/or storable energy such as electric current/voltage. Some embodiments include methods and apparatus for transferring heat from a suspension and further include methods and apparatus for generating power required to operate heat transfer enhancement mechanisms. Some embodiments include methods and apparatus for automatically regulating power generation and/or heat transfer enhancement. Some embodiments include methods and apparatus for adjusting damping fluid flow rates to change damping rates in proportion to changes in suspension temperature. Some embodiments include dynamically adjustable dampening fluids for altering damping rates in proportion to external input. Some embodiments include methods and apparatus for separating gas and liquid phases of damping fluid to tend to return damping fluid to a pre-use state.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features can be understood in detail, a more particular description, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only certain embodiments and are therefore not to be considered limiting, for the invention may admit to other equally effective embodiments.

FIG. 1 shows a telescopic bicycle fork.

FIG. 2 shows a suspension locking mechanism.

FIG. 3 shows a suspension locking mechanism.

FIG. 4 shows a suspension damper including a linear generator and a cooling circuit.

FIG. 5A shows a bicycle shock absorber according to one embodiment.

FIG. 5B shows a detailed portion of the shock absorber of FIG. 5A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

One embodiment hereof will be described as applied to a bicycle fork. It will be appreciated that such embodiments are equally applicable to rear suspension units or other suspension units that include relatively movable parts that may be selectively immobilized in relation to one another.

Referring to FIG. 1 of U.S. Pat. No. 6,217,049; shown is a front fork assembly. A modified copy of the FIG. 1 is included as FIG. 1 herein and has been marked with a view A-A. Inner

tube 16 is shown telescopically extending within outer tube 18 wherein the tubes 16, 18 have a substantially common longitudinal axis.

FIG. 2 shows an embodiment of a mechanical suspension lock schematically depicted within portion A-A as specified in FIG. 1 including tubes 16,18 and wiper (not numbered). FIG. 2 shows an embodiment of a system for immobilizing tube 16 relative to tube 18 thereby allowing for selective creation of a rigid fork comprising tubes 16 and 18. The incidence of other dampening components inside the fork tube or tubes is of no consequence regarding the shown embodiment. FIG. 2 shows a modified outer tube 18. The tube 18 includes an annular recess 4 and a substantially incompressible elastic element 1 is contained within the recess 4. The elastic element 1 may comprise any suitable material such as, for example, elastomer, rubber, or thermoplastic. In one embodiment a feature of the elastic element 1 is that due to its substantial incompressibility, and bulk modulus, a first force exerted in one direction one the element will cause corresponding deformation of the element 1, and force exertion by the element 1, in a direction substantially orthogonal to the first force. In lay terms the element 1 may be exemplified as a rubber donut. When compressed axially and constrained radially by the outer surface (inside tube 18) of the recess 4, the compressed donut will bulge inwardly (and exert pressure outwardly against the constraint) until it contacts and becomes constrained by the outer surface of the inner tube 16. Once the element 1 contacts the inner tube 16 it will exert a force (pressure over the area corresponding to the length of contact) on the outer surface of tube 16 proportional in magnitude to the axial compression force exerted on element 1. Such a force can be quite high, particularly if the axial contact length and circumference (area) are significantly great (note: the force can be adjusted by design and one factor is the chosen contact area). The frictional constraint between the element 1 and the tube 16 will be a function of the normal force (or force per unit area) between the parts and the coefficient of friction. By application of a sufficient axial force on element 1, which is contained within and fixed relative to tube 18, the inner tube 16 and the outer tube 18 can be relatively immobilized thereby resulting in a simple and rigidly locked out suspension system. Principles of expanding elastomer elements are described in U.S. Pat. No. 5,813,456 which is incorporated, in its entirety, herein by reference. Note that the principles described therein are in reference to a rubber element that expands radially outward in response to an applied axial force.

In the embodiment of FIG. 2, axial force is applied to the element 1 by a threaded element compression nut 2. A rider may optionally turn the compression nut, for example clockwise, so that right hand inter-engaged threads (compression nut male thread 6 and recess 4 female thread 5) cause the compression nut 2 to move axially deeper into recess 4 thereby compressing element 1 and bulging element 1 into contact with an outer surface of tube 16. The effect of that movement is shown in the "before and after" respectively left and right of centerline views in FIG. 2. Note that the nut 2 is advanced downwardly in the right side view.

In one embodiment axial force is applied to element 1 by means of a cable operated annular ball cam mechanism. In one embodiment nut 2 is replaced by a rotational cam and element 4 is capped by a solid washer (e.g. metallic). Cam balls are interposed between the cam and the washer and the balls are recessed into semi-spherical cavities in the washer (such that they remain in fixed location relative to the washer). The balls are engaged by rotational cam surfaces on the cam nut 2'. A cable is configured to be manually operable from a

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cockpit of the vehicle and in operation to pull the rotational cam **2'** to rotate about the axis of tubes **16, 18**. Such rotation causes the cam to force downwardly on the balls thereby exerting an axial force on the washer and correspondingly on element **1**. Cylindrical ball cam mechanisms are described in U.S. Pat. Nos. 6,199,669 and 6,520,297, each of which is incorporated herein, in its entirety, by reference.

FIG. **3**. shows a slightly modified detail section B-B of FIG. **2**. The modification of FIG. **3** over FIG. **2** relates to an optional embodiment for the element **1** of FIG. **2** and that element is designated element **3** in FIG. **3**. The recess **4** of FIG. **3** has a modified lower surface **9** where that surface is inclined at some angle **8** relative to a plane perpendicular to the longitudinal axis of the tubes **16,18**. The element **3** is optionally a solid 'C' shaped ring or segmented ring having an angle corresponding to angle **8** beveled on a lower surface thereof. When element **3** is moved axially downward, by for example compression nut **2** as previously described, the angle on element **3** interacts with the angle **8** thereby urging element **3** radially inward into contact with an outer surface of tube **16**. The amount of radial inward force is a function of the force exerted on element **3** by nut **2** and the tangent of angle **8**. The axial/radial force relationship may be adjusted using those design variables. It may be appreciated that element **3** may be urged into a diametrical recess (not shown) in a surface of tube **16**. It may also be appreciated that any of the components shown to be directed radially inward may be directed radially outward and vice versa. In other words the element **1,3** may be on an exterior recess of an inner tube and the axial force may urge the element radially outward toward an inner surface of an outer tube. Principles of segmented gripping rings or "slips" are described in U.S. Pat. No. 5,813,456 which is incorporated herein, in its entirety, by reference.

While the gripping and immobilizing system embodiments shown herein depict a particular location on a suspension unit it will be appreciated that such components, in the same, or alternative embodiments may be positioned at almost any location inside a suspension dampening fluid chamber or external of such chamber (external example shown) and elsewhere on the suspension so long as two relatively moving components of the suspension are accessible by design for integration of a gripping system. It is appreciated that the suspension to be mechanically locked may be any suitable suspension (e.g. that suspending wheels, seats, integral to seat posts, machinery). It is appreciated that relatively moving parts may be affixed to moving suspension parts for the specific purpose of using such affixed parts for immobilization. It may be appreciated that an elastic element **1** may allow for some vibration damping between tubes **16,18** thereby providing a more comfortable bicycle ride while minimizing pedal bounce.

The U.S. Pat. Nos. 5,186,481, 7,147,207 and 6,217,049, as well as others, describe suspension units in which bounce is minimized (not eliminated) with the use of hydraulic "lock out" valves. Such valves, regardless of specific fork designs or configurations, all operate to close or throttle the damping fluid flow path whereby fluid would normally flow out of a compression side chamber formed by a dampening piston. When the suspension is "locked out" the bounce is the suspension is typically limited by the compressibility of damping fluid "locked in" the compression chamber of the suspension unit. Unfortunately, bounce remains in the system and is the volume of the "locked" compression chamber is large such bounce (system compressibility) can be significant.

Hydraulic lock out suspension systems are equipped with a pressure relief valve that bypasses (or otherwise relieves) the lock out valve when pressure in the compression chamber

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reaches a certain value. That pressure relief valve or "blow off valve" is necessary in case a large force is imparted to the suspension while "locked out." As force is imparted to the locked out suspension pressure in the compression chamber is increased. A large enough force may generate a fluid pressure high enough to damage components of the suspension (e.g. burst the compression chamber). Because the magnitude of possible forces is difficult to limit, a blow off valve is added to relieve over-pressure corresponding to such a force. Blow off valves and related "compression chambers" are described in U.S. Pat. No. 7,163,222 and US Patent Application Publication No 2007/0007743, each of which is incorporated herein, in its entirety, by reference.

Because the lock out system and blow off valves of hydraulic lock out systems are fluidic in nature they are subject to malfunction if contaminated by for example particulate matter. Furthermore, the performance of such systems depends on fluid properties such as viscosity and shear strength and those properties are subject to change with time and with temperature.

Because the lock out system is hydraulic, complexity is added to the suspension. Additional components include a lock out valve and associated adjustment controls, a blow off valve and associated adjustment controls and other associated hydraulic system control mechanism feed through and seals.

While the suspension lock out system described herein may be used to limit vehicle movement by "locking" the suspension, one embodiment accommodates issues that are relevant when the suspension is active (i.e. when the lock out is not engaged). Because a vehicle suspension system **100** is, when in use, constantly subjected to alternating forces and is compressed and extended cyclically in response to those forces, such vehicle suspension may, in one embodiment, be configured for use as a bi-directionally acting linear motor. In one embodiment, one of the damping piston rod (shaft) **105** and the damping cylinder **110**, or portion thereof or attached thereto (structure through which the piston rod moves axially), is configured to include a wire motor winding **115** and the other of the cylinder **110** or piston rod **105** configured to include one or more permanent magnets **120**. The relative and cyclic axial movement between the rod and the cylinder (i.e. the magnet and the winding) produces an electric current within the winding. FIG. **4** shows a suspension **100** including a winding **115** within a wall of a damping cylinder **110** and a permanent magnet **120** within a piston rod **105**. The winding power output terminals **125** extend through an out housing of the suspension **100** and are available to conduct generated electric power to its point of use. U.S. Pat. Nos. 6,952,060; 3,842,753; 4,815,575; 3,941,402; 4,500,827; 5,578,877; 5,347,186; 5,818,132; 3,559,027; 3,861,487; 3,921,746; 3,981,204; 5,036,934; 7,569,952; 4,032,829; and 4,387,781, each of which is incorporated, in its entirety, herein by reference, describe various linear generator (e.g. linear motor based) configurations for using reciprocal motion to generate electrical power.

In one embodiment, a cooling circuit **130**, such as a thermo-electric generator (e.g. "TEG" described in greater detail herein), is attached to a wall **110** of the damping cylinder to facilitate heat transfer between the cooling circuit **130** and the wall **110**. Electric power is conducted, via conductors **140**, from the winding terminals **125** to the input terminals of a power conditioner **135**. The power conditioner **135** may be any suitable power conditioner, such as for example an AC/DC converter, a DC/DC converter, a transformer, a battery, a capacitor or any suitable combination thereof or other suitable conditioner as may be required to power the cooling circuit **130**. Conditioned power is conducted, via conductors

140, from the output terminals of the power conditioner 135 to the input terminals 145 (typical) of the cooling circuit 130. As the piston rod 105 moves back and forth axially in direction 150, the magnet 120 moves relative to the winding 115. That cyclic movement generates and electric current within the winding 115 which as described powers the cooling circuit which in turn conducts heat away from the damper 100.

As an alternative or additional option, piezo electric crystals may be attached to a portion of the piston that is subjected to axial fluid pressure induced forces during operation of the suspension. In one embodiment an area along the piston "skirt" or near the edge where proximity to the walls of the cylinder through which the piston moves, creates a high fluid shear force in the fluid layer between the cylinder and the piston. Such shear stress in the fluid (i.e. viscous drag) operates to deform the piezoelectric crystal thereby generating a current. The piezoelectric structure is deformed cyclically at each reversal of piston direction (cyclic stroke of the suspension) and in response to such deformation the piezo generates a electric current. In one embodiment the piezoelectric structures may be placed on a face or faces (front/back, top/bottom, compression/rebound) of the piston and deformation of the piezo structure(s) is induced by dynamic fluid pressure buildup due to damping force generation. In one embodiment piezoelectric devices are places proximate the ends of the damping cylinder and dynamic fluid pressure generated by damping action acts on those devices during compression and/or rebound pressure buildup. In one embodiment, piezoelectric structures are placed within a damping piston such that fluid flow generates dynamic vibration of the piezoelectric structures and thereby generates electric power. It is noteworthy that while a damping piston and cylinder are used herein to exemplify embodiments of an electric current and/or voltage generating shock absorber, the principles disclosed herein are equally applicable to a gas spring piston and cylinder combination of a suspension. Further, the piezoelectric devices may be places at an end or ends of a compression spring of a vehicle suspension thereby generating current during deformation of the piezoelectric structure under cyclic spring loading and corresponding axial force on the piezoelectric structure. Optionally a mechanical spring such as a coiled spring may comprise and electric winding or permanent magnet of the linear motor described herein. A plurality of piezoelectric devices may be placed on the piston faces and/or the piston skirt or any suitable combination thereof. A vehicle suspension may be equipped with a combination n of piezoelectric generators and linear motor structures. For purposes hereof, discussions of electric motors and generators are substantially interchangeable. In principle an electric motor generates movement when a current is applied thereto. Conversely the same structure will generate electric current when movement is applied thereto. Such is particularly applicable to piezoelectric structures and therefore examples of piezo motors included herein are suitable as examples of electric generators and vice versa. U.S. Pat. Nos. 5,806,159; 5,872,418; and 7,208,845, each of which patents is incorporated, in its entirety, herein by reference, describe piezoelectric generators and motors that are suitable for use in embodiments hereof. FIG. 4 shows a piezoelectric generator 155 (e.g. of the flow operated type described in U.S. Pat. No. 7,208,845) fixed within a fluid flow path 160 through piston 165. As the piston 165 reciprocates, during operation of the damper 100, fluid flowing 160 causes piezo generator 155 to vibrate (e.g. at resonance) thereby generating electric output. Such electric output is conducted, via conductors (not shown) through piston rod 105 and such conductor output terminals

may be located at an end (not shown) of piston rod 105. Any suitable combination of the foregoing may be used.

Thermo-Electric generators or "TEG"s are special circuits that EITHER remove heat from one surface (the "cold" surface) of the circuit to another surface (the "hot" surface) upon application of an electric current to the circuit OR generate a current upon application of a temperature differential across the opposing "hot" and "cold" surfaces of the circuit. In one embodiment, TEGs may be based on the Peltier Effect and correspondingly constructed from thin ceramic wafers having alternate P and N doped bismuth telluride sandwiched between them. Such TEGs may be simply constructed using thermoelectric materials such as lead telluride, germanium telluride and cesium telluride. Other thermoelectric effects (and mechanisms usable in accordance herewith) include the Seebeck Effect and the Thomson Effect. U.S. Pat. Nos. 6,141,969; 7,523,617; 5,040,381; and 5,687,575, each of which is incorporated, in its entirety, herein by reference, describe the principles of thermo-electric circuit operation and application.

In one embodiment, as shown in FIG. 4, a damping piston shaft (or rod) 105 and a corresponding damping cylinder 110 are equipped, as disclosed herein or otherwise, to generate electric current (or voltage if open circuit) in response to relative movement there between. At least a portion of the housing of the damping system is equipped with at least one TEG(s) 130 such that the "hot" surface of the TEG is in primary thermal communication with the ambient surroundings of the damping system (or a secondary cooler, or a heat sink, or a combustion engine intake manifold or any environment suitable for heat use or disposal) and the "cold" surface of the TEG 130 is in primary thermal communication with the damping structure (e.g. damping fluid) 110. Such thermal communication may be facilitated by direct contact or may be via a suitable thermal conduit (not shown). A current is generated by operation of the generator equipped suspension 100 and at least a portion of that current is connected to operate the TEG(s) 130. Optionally a heat sink (not shown) may be included and placed in thermal communication with the "hot" side of the TEG 130. Such a heat sink aids in conducting heat away from the suspension 100 and may be equipped with heat dissipation mechanisms such as cooling fins. If the vehicle suspended by such TEG equipped suspension 100 further includes a water cooling (or other powered cooling) system, the heat sink may advantageously be placed in thermal communication with such cooling system.

Typically, a suspension system comprising an electric generating embodiment and TEG(s) as disclosed herein generates more electricity when subjected to extremely "bumpy" terrain versus relatively smooth terrain. Although the bumpy terrain will generate more heat in the suspension (and correspondingly more heat build up potential), the higher current flow, caused by more frequent cycling of the suspension, from the electric generating systems (as disclosed herein) will provide more power to the TEG(s) and will correspondingly result in a greater "heat split" (up to the limit of the TEG) between "hot" and "cold" TEG surfaces. Such greater heat split will result in a higher cooling rate for the suspension. In lay terms: the harder the auto-cooling suspension hereof is worked, the more it will tend to cool itself off.

Optionally the suspension system can be "smart" such that the TEG(s) only activates when needed. In one embodiment a simple temperature sensor (proximate the damping fluid and not shown) and microprocessor (e.g. the power conditioner 135 may include or comprise a programmable or preprogrammed microprocessor and power output switch or modulator) controlled switch turn the TEG on and off or modulate

current flow thereto based on operating temperature of the suspension **100**. In one embodiment, there is an intermediate cylinder (not shown) mounted coaxially between the piston shaft and the damping cylinder. The intermediate cylinder, rather than (or optionally in addition to) the piston shaft, includes either the magnet or the winding (and/or piezoelectric structures) and the damping cylinder (or air spring cylinder) there around includes the other of the winding or magnets. In such an embodiment, relative axial movement between the intermediate and damping cylinders generates electric current (solely or in addition to other current generating mechanisms present in the suspension thereof). In one embodiment there is a layer of fluid (e.g. damping fluid) between the intermediate cylinder and the damping cylinder. At lower (e.g. ambient or normal operating) temperatures, the viscosity and shear strength of the damping fluid are such that the oscillation of the piston shaft within the intermediate cylinder are insufficient to cause substantial movement of the intermediate cylinder within the damping cylinder (i.e. the fluid between the intermediate and damping cylinders is strong enough that the frictional forces therein maintain a dynamic axial “fix” between the intermediate and damping cylinders). As such, at low temperature no significant electrical current is generated in response to the configuration of the intermediate cylinder within the damping cylinder because they are not relatively movable. When, however, the damping unit heats up in response to more vigorous use, the fluid layer between the intermediate and damping cylinders becomes less viscous (i.e. “thinner”) and the frictional force of the piston moving within the intermediate cylinder, in addition to providing damping, causes the intermediate cylinder to move axially relative to the damping cylinder. The relative movement of the intermediate and damping cylinders generates electric current which in turn may operate at least one TEG(s) affixed to the damper. The intermediate and damping cylinders will continue in relative axial movement until the system is sufficiently cooled by the TEG(s) to allow the fluid between those two cylinders to “thicken” and thereby once again “lock” the cylinders from relative axial movement (until they become reheated due to lack of cooling and the cycle begins again).

Optionally a suspension comprises TEG(s) placed suitably in relation to heat generating portions of the suspension and the TEG(s) generate electric current in response to the heating of the suspension in use. The heat generated by the suspension actually powers the TEG, causing it to generate electric current. In FIG. 4 such a configuration would include the TEG **130** wherein the TEG terminals **145** would, in this TEG electric generator embodiment, represent electric output terminals from which usable electricity may be conducted to a suitable power use point (e.g. battery, valve, capacitor). When the TEG electric output leads are shunted or connected to a high current input battery (or capacitor) through a suitable current conditioner (e.g. DC/DC converter) the current flow will facilitate the passive conduction of heat away from the suspension (to be used in generating current). The correspondingly generated current may be used to power “smart” systems associated with the suspension and/or the vehicle generally. Note that any or all of the foregoing electricity generating systems may be used in any suitable combination.

U.S. Pat. No. 7,374,028 (the “’028” patent), which is incorporated, in its entirety, herein by reference, describes a bicycle shock absorber having a “piggy back” gas charged damping reservoir. Optionally, electric current and/or voltage generated as disclosed herein may be used to control at least one valve opening(s) within the damping system such that at lower fluid viscosities (e.g. higher temperatures), for

example, valves are closed or throttled. FIG. 5A shows a shock absorber of U.S. Pat. No. 7,374,028 subject to the present modification from that Patent as shown in FIG. 5B and as further described herein. In one embodiment valves control the flow of damping fluid (and hence the damping rate) and when adjusted may compensate for varying viscosity of the damping fluid. Suspension may include a gas pressure charge or chamber in pressure communication with the damping fluid (e.g. oil) to control or set static damping fluid pressure. As the suspension heats so the gas charge may heat and thereby increase the static pressure of the damping fluid disadvantageously. In one embodiment the cooling system hereof operates to cool the gas charge thereby providing a stable static damping fluid pressure.

Referring to FIG. 5A herein (from the ’028 patent), intensifier assembly **510** is shown in conjunction with damper assembly **630**. FIG. 5B shows an embodiment of an intensifier valve **511** for use with the principles disclosed herein. In one embodiment the intensifier valve **511** of FIG. 5B replaces the assembly **510**, as shown in FIGS. 15, 17 of the ’028 patent and elsewhere in the ’028 patent. The valve **511** is operable in response to electric current and is capable of being modulated or throttled for selective full opening, closing and intermediate opening or “throttle” positions. Operation of the valve is generally described in U.S. Pat. No. 7,299,112 which is incorporated herein by reference. It should be noted that **122** and **124** are interchangeable such that the voice coil may be either **122** or **124** and the magnet may be the other of **122** and **124** respectively. The voice coil **122** or **124** responds to input current from the power circuit (e.g. position control circuit or other suitable electrical input as described herein). As such input wiring is desirable. The input wiring and terminals for the **122** version of the voice coil is shown at **250**. The input wiring and terminals for the **124** version of the voice coil is shown at **251** and includes windings **252** to accommodate extension and contraction of the throughput wires **252** during operation of the valve **200**.

The valve **200** is shown in a closed, or downward **256**, position. As such, piston **116** fully obstructs orifices **114** thereby preventing fluid from flowing from damper assembly **630**, through channel **636**, into upper chamber **253**, through orifice **114**, through valve outlet **257** and into floating piston compensator chamber **254**. When current of an appropriate magnitude is applied to the voice coil **122** or **124**, the magnet electromagnet combination of **122** and **124** causes the back iron **126**, and correspondingly the valve piston **116**, to move upward **255** in an amount proportional to the voice coil input. Such upward **255** movement is against spring **118**, which biases the valve piston **116** downward **256** (i.e. toward closed), and therefore when the voice coil input balances with the force of spring **118**, movement of the piston **116** will stop and the valve **200** will be correspondingly throttled.

In operation, referring also to FIG. 4, the sensor (or generator) **155** or **120/115** or both puts out a voltage change corresponding to an induced relative movement of the rod **105** and cylinder **110** of the damper **100**. In one embodiment the sensor senses input force along a prescribed axis **150**. As described herein. Generated power may be routed through the power conditioner **135** which may in turn send power to the valve of FIG. 5B. In one embodiment, the valve of 5B is biased open (not shown by extending the length of valve **116** downward (direction **256**) and placing a hole in **116** adjacent the hole **114**, as the valve **116** is moved upwardly by applied electric current, the holes become misaligned thereby closing the valve **511**) and is closed gradually in response to increasing power input to terminals **250** or **251**. As the shock damper **100** is worked more frequently, it generates more power and

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heat. The heat causes damping fluid to become thinner. In order to optimize performance as heat increases it is desirable to close the damping fluid valve **511** thereby providing greater restriction to flow and maintaining damping rate. A similar result may be obtained by using TEG **130** in a passive heat removal role as an electric generator. In one embodiment, current is conducted from the TEG to the terminals **251** or **250** of the open biased (not shown but described herein) valve **511**. As the TEG heats up it causes a closure of valve **511** in response thereto and thereby compensates (maintains damping rate) the damper for increased temperature.

Referring additionally to FIG. **4**, when the sensor **120/115** puts out a voltage corresponding to a bump (and/or optionally a dip) that voltage is transmitted to a processor **135**. In one embodiment the shock absorber of FIGS. **4** and **5** including valve **511** is responsive to signals and power transmitted to the valve (e.g. at **251**, **250**) from the controller **135**. The valve **511** is default in the closed position and will throttle open corresponding to power input received at terminals **250**. The processor **135** compares the output voltage of sensor **155** or **120/115** to a preset (by means of threshold adjuster) value and if that value is exceeded, the controller routes a predetermined amount of power from the power source (battery and/or capacitor not shown or **120/115** or **130** or other generator directly) to the valve **511**. When the output voltage falls below the threshold value, power to the valve **511** is shut off. Optionally the valve **511** may be of a type described in U.S. Pat. No. 6,073,736 which is incorporated, in its entirety, herein by reference. Optionally, the valve control/power circuit may be configured and operable in a manner such as disclosed in U.S. Pat. Nos. 5,971,116 and 6,073,736 each of which is herein incorporated, in its entirety, by reference, or by any other means or method disclosed herein or any suitable combinations or portions thereof.

In one embodiment a mechanism that transduces temperature change into physical movement is used to operate at least one damping valve(s), thereby compensating the damping rate for temperature changes. Referring to FIG. **5B**, and in the context of the herein described application thereof, one embodiment includes a bimetallic (or bi-material composite) spring **118** or element placed in thermal communication with the damping fluid. As the damping fluid heats, during use, the bimetallic element deforms (e.g. curls or bends) in response to the different thermal expansion coefficients of the two dissimilar metals composing the element. The bending or movement of the element is used to operate valve member **116** toward a closed position. In such embodiment a second “regular” spring (not shown) is retained axially, in fixed relation to body **273**, within space **257** such that the “regular” spring exerts an axial upward **255** force on valve **116** thereby biasing it open. The bimetal spring **118** must be heated enough by damping fluid so as to overcome the biasing force of the “regular” spring. As such, when the damper is sufficiently cooled the “regular” spring opens the valve **511**.

Generally bimetal strips, springs or other elements may be used to operate a valve as desired (e.g. close, open, choke or throttle) within the damping fluid chamber (e.g. on the damping piston) to modulate the damping fluid flow area as desired in view of the temperature induced damping fluid changes. (e.g. close or choke valves to compensate for thinner damping fluid). U.S. Pat. Nos. 5,381,952 and 4,131,657, each of which is incorporated herein, in its entirety, by reference, describe configurations and applications for bimetal actuated valve members.

Optionally, temperature change may be converted to physical movement using “shape memory” alloys such as Nitinol (a Raychem trade name for a nickel-titanium shape memory

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alloy) or certain two phase brass alloys having shape memory characteristics (also available from Raychem). Valve operating mechanisms may comprise shape memory alloys programmed to change shape at a certain “trigger” temperature and thereby operating a damping valve or valves using motion in between their original and programmed shapes. Shape memory alloys may, with minimal if any alteration in design, be used in place of bimetal elements and vice versa as temperature sensitive operational characteristics are similar. The bimetal valve spring as described herein may alternatively be a Nitinol (or other shape memory alloy) spring. U.S. Pat. Nos. 6,840,257; 6,073,700; and 4,570,851 each of which is incorporated herein, in its entirety, by reference, describe configurations and applications for shape memory alloy actuated valve members. In one embodiment, the valve shown in U.S. Pat. No. 6,840,257 may be placed within the flow path **160** of FIG. **4** thereby modulating damping fluid flow through piston **165** in response to damping fluid temperature changes. Optionally the flow path **160** may be substantially closed off except for a flow path through a valve or valves placed therein.

Any valve operator mechanism disclosed herein may be used with one or more valves of a multi-valve damping system (or other suspension system such as spring) such as for example where two valves are open for “cold” temperature suspension operation and one valve is closed for “hot” suspension operation.

Optionally temperature or strain rate (i.e. induced damping rate) compensation mechanisms include shear thickening fluids (liquids). Such liquids increase in strength as shear stress is applied. In one embodiment such a fluid becomes more resistant to flow through an orifice (e.g. in a damping system) as the flow rate requirement or induced damping rate is increased. In lay terms: the harder a suspension, containing a shear thickening damping fluid, is “hit”, the more rigid the suspension will behave because the damping force is rate dependent. Electro-thickening or magneto-resistive liquids can be used to a similar end if an electric current is applied to such liquid in proportion to the induced damping rate (the induced damping rate being induced by, and proportional to, the severity of the impact imparted to the suspension). In one embodiment electrical generators as disclosed herein power a magnetic coil surrounding a portion of a magneto-resistive damper. As the suspension is operated, electrical current is generated in proportion to the rate of operation (impact rate) and the current flows through the magnetic coil. The energized magnetic coil causes the magneto-resistive fluid to thicken there by increasing the damping rate. Alternatively a generator as disclosed herein (or a battery/capacitor) is switched to apply current to the magnetic coil when induced operation rates are low (and/or of low amplitude) and to bypass the magnetic coil as induced operation rates increase. As such the suspension will exhibit more damping compliance (lower damping rate) when induced operational rates increase.

When gas becomes entrained in a damping liquid, the apparent density of the emulsified liquid is reduced. That can happen when an “open bath” damper is used vigorously over a period of time. The gas and liquid in the damper become commingled at the gas/liquid interface and as use continues, the intermingled fluid migrates through the damping system until the damping mechanism is at least partially subverted (because less dense fluid flows more rapidly through metering channels and various orifices that facilitate the dampening effect). One option for dealing with entrained gas is to include a mechanical “gas buster” in the fluid flow path within the dampening mechanism. One complicated example of a “gas buster” or separator is a mechanical cyclone. Mixed gas/

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liquid (e.g. emulsion) enters the cyclone tangentially at a major diameter of the cyclone so that the mixture flows in a substantially tangential spiral within the cyclone. Due to centrifugal force, the less dense gas migrates toward the longitudinal axis of the cyclone (about which flow spirals) and exits the cyclone on the axis at the top. The more dense liquid phase continues in tangential flow downward in a decreasing diameter toward an outlet at the bottom of the cyclone. The “top” and “bottom” of the cyclone are relative though such terms are often used in relation to the earth. In one embodiment, a miniature cyclone is placed on a piston movable through a damping fluid filled cylinder. The top of the cyclone is attached to a flexible, or telescopic, tube that has an outlet end in fluid communication with a region of the suspension damper normally containing gas. The lower end of the cyclone is in fluid communication with a trailing side of the piston and the cyclone inlet is in communication with a leading side of the piston. Such a piston would “scrub” the damping fluid of gas on every stroke of the piston through the damping cylinder. In one embodiment the separator comprises an abrupt 180 degree flow direction change. The principle of the 180 degree bend or flow tube is similar to that of the cyclone in that they both rely on the fact that the kinetic energy of the liquid is greater than the kinetic energy of the gas traveling at the same velocity. A 180 degree bend tube includes exit ports at the bend and the liquid layer, being at the outside radius of the bend, will exit through the ports while

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the gas will continue through the bend. The separate gas and liquid streams may be disposed of as described herein.

While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What we claim is:

1. A vehicle suspension comprising:
 - a first support member;
 - a second support member, said first support member and said second support member being movable relative to one another along a substantially common axis, wherein a damper having a damping fluid is disposed between said first support member and said second support member; and
 - a valve assembly configured for one of opening and closing in response to an electric current, said valve assembly comprising:
 - a sensor, wherein said sensor is configured for sensing a change in a characteristic of said damping fluid caused by said relative movement between said first support member and said second support member and for responding such that said electric current is generated.
2. The vehicle suspension of claim 1, wherein said responding comprises: deforming.

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